Sexual anatomy of the flounder *Citharichthys spilopterus* (Paralichthyidae)

by

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Abstract. – The Bay whiff *Citharichthys spilopterus* is distributed from New York to the south of Brazil. In order to know their reproductive anatomy, several specimens were collected during an annual cycle in the lagoon Tampamachoco, Veracruz, Mexico. This species shows, like other Pleuronectiformes, a reduction in the size of the visceral cavity, due to the forward displacement of the anal fin. This change implies a reversal position of the reproductive system in both sexes, so that oviducts in females and sperm ducts in males are oriented forward and open through the genital papilla and the urogenital papilla, respectively, in a position distinctly anterior to that of most teleosteans. The reduction of the visceral cavity causes the ovaries to develop extra viscerally toward the caudal region into the so-called "secondary body cavities", between the hypoaxial musculature and the anal fin pterygiophores. In males, the gradual modifications of the spermatic ducts during maturation are especially noticeably, consisting in their multiplication and anastomosis. This anatomical condition of the male reproductive system of *C. spilopterus* represents the morphological model of the Paralichthyidae family, but not that of the Achiridae and Cynoglossidae families. According to the gonadosomatic index for both sexes, the breeding seasons are from January to April and from September to November.

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Résumé. – Anatomie sexuelle de *Citharichthys spilopterus* (Paralichthyidae).

Le "rombou de plage" *Citharichthys spilopterus* est réparti de l'état de New York, aux États-Unis, jusqu'au sud du Brésil. Afin de connaître l'anatomie du système reproducteur, plusieurs spécimens ont été recueillis au cours d'un cycle annuel dans le lagon Tampamachoco, Veracruz, au Mexique. Cette espèce montre, comme les autres Pleuronectiformes, une réduction de la taille de la cavité viscérale due au déplacement vers l'avant de la nageoire anale. Ce changement implique une position inversée du système reproducteur chez les deux sexes, de sorte que les oviductes chez les femelles et les spermiductes chez les mâles sont orientés vers l'avant et s'ouvrent vers l'extérieur par les papilles génitale et urogénitale, respectivement, atteignant une position nettement antérieure à celle de la plupart des téléostéens. La réduction de la taille de la cavité viscérale induit les ovaires à croître en position extra-viscérale, vers l'arrière, dans les régions appelées "cavités corporelles secondaires", entre la musculature hypoaxiale et les ptérygiophores de la nageoire anale. Chez les mâles, des modifications progressives et particulièrement notables des spermiductes sont observées au cours de la maturation des gonades. Ces modifications consistent en une multiplication des "canaux" spermatiques qui deviennent anastomosés et remplis de sperme. Cette condition anatomique du système reproducteur mâle de *C. spilopterus* représente le modèle morphologique de la famille Paralichthyidae mais pas celui des familles Achiridae et Cynoglossidae. L'indice gonadosomatique établi chez les deux sexes indique que les saisons de reproduction se situent de janvier à avril et de septembre à novembre.

Key words
Paralichthyidae
Citharichthys spilopterus
Gonads
Ovaries
Testes

Flatfishes (order Pleuronectiformes) are teleosts with the body laterally flattened, both eyes on the same side, and with dorsal and anal fins with long bases (Norman, 1934). According to Nelson (2006), there are about 678 species of Pleuronectiformes, distributed in 14 families, Paralichthyidae being one of the most important with 105 species, among which there is the flounder *Citharichthys spilopterus* Günther, 1862. This species ranges from New York to southern Brazil (Robins and Ray, 1986), and enters regularly brackish waters. It is the most common flatfish in coastal lagoons of the Gulf of Mexico (Reséndez-Medina and Kobelkowsky, 1991), and it is especially abundant in the Tampamachoco lagoon in the state of Veracruz, Mexico (Castillo-Rivera and Kobelkowsky, 1992). According to Sánchez-Gil *et al*. (2008), *C. spilopterus* is one of the most abundant species of flatfishes in the southern Gulf of Mexico.

While the feeding biology of *C. spilopterus* has been researched (Castillo-Rivera *et al*., 2000), studies regarding the reproductive aspects of this species have been scarce. Some of them include the reproduction of *C. spilopterus* by Chaves and Vendel (1997) in the Bay of Guaratuba, Brazil, and by Dias *et al*. (2005) off the coast of Rio de Janeiro, Brazil.

The few studies on the morphology of the reproductive system of the genus *Citharichthys* are those of Hoshino *et al*. (2004), who described the sexual dimorphism in the urogenital papilla of *Citharichthys platophrys* Gilbert, 1981, and Kobelkowsky (2007) who described these structures in *C. spilopterus*.

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Although, some ancient literature gives some information on reproduction of Pleuronectiformes (Fabre-Domergue and Biétrix, 1905), most of them lacking detailed information about reproductive anatomy. Among the scarce studies on the gross anatomy of the reproductive system of Pleuronectiformes are those of García-López *et al.* (2005) on *Solea senegalensis,* and Chanet (2012) on *Pegusa lascaris*, while other studies only emphasize histological aspects (Oliveira and Fávaro, 2010; Viñas *et al*., 2013; Ghaffari *et al*., 2015).

Considering the ecological importance in the demersal fish community, the objective of the present study is the description of the reproductive system and its anatomical changes during the reproductive annual period of the flounder *C. spilopterus* from the costal lagoon of Tampamachoco, Veracruz, Mexico.

MATERIALS AND METHODS

The Tampamachoco lagoon is located in North Veracruz State (21º03'-06'N, 98º36'-42' W), in the western Gulf of Mexico near Tuxpan City. Specimens were collected monthly during an annual cycle by means of a shrimp trawl net, and were fixed in 10% formaldehyde and stored in 70% ethanol. For anatomic analyses, a sample of 80 specimens, 34 females and 46 males, was examined.

The visceral cavity was exposed, removing the body wall from both sides, including the skin, axial musculature and ribs. Anatomic analysis of the visceral cavity and its organography was made under a stereoscopic microscope. Gonads were removed from both sides.

The gonadosomatic index (GSI) was calculated as:

$$(\text{Gonad weight} / \text{Total body weight}) \times 100$$

For GSI analyses, a sample of 335 specimens, 134 females and 201 males was examined. The male gonad weight included testes and spermatic ducts.

Three ovaries and five testes were fixed in Zamboni solution (Martínez and Grageba, 2008) for histological purposes. Histological analysis of ovaries, testes and spermatic ducts was made by means of 6.0 microns cross sections, stained with haematoxylin and eosin, and Masson trichrome.

For comparative purposes, the following species were used:

Paralichthyidae: *Citharichthys spilopterus* Günther, 1862 (IBUNAM:CNPE:PE255), *C. macrops* Dresel, 1885 (IBUNAM:CNPE:PE2527), *Syacium papillosum* (Linnaeus, 1758) (IBUNAM:CNPE:PE10126), *S. micrurum* Ranzani, 1842 (IBUNAM:CNPE:PE9314), *S. gunteri* Ginsburg, 1933 (IBUNAM:CNPE:PE1718), *Cyclopsetta fimbriata* (Goode & Bean, 1885) (IBUNAM:CNPE:PE5948), *C. chittendeni* Bean, 1895 (IBUNAM:CNPE: PE4235), *Ancylopsetta ommata* (Jordan & Gilbert, 1883) (IBUNAM:CNPE:PE7952), *Etropus crossotus* Jordan & Gilbert, 1882 (IBUNAM:CNPE:PE2282), *Paralichthys lethostigma* Jordan & Gilbert, 1884 (IBUNAM:CNPE:PE8624).

Pleuronectidae: *Pleuronichthys ritteri* Starks & Morris, 1907 (IBUNAM:CNPE:PE1472), *P. verticalis* Jordan & Gilbert, 1880 (IBUNAM:CNPE:PE1473), *Poecilopsetta beanii* (Goode, 1881) (IBUNAM:CNPE:PE9863).

Bothidae: *Engyophrys senta* Ginsburg, 1933 (IBUNAM:CNPE:PE9211), *Bothus robinsi* Topp & Hoff, 1972 (IBUNAM:CNPE:PE1776), *Trichopsetta ventralis* (Goode & Bean, 1885) (IBUNAM:CNPE:PE9328).

Achiridae: *Achirus lineatus* (Linnaeus, 1758) (IBUNAM:CNPE:PE4921), *Trinectes maculatus* (Bloch & Schneider, 1801) (IBUNAM:CNPE:PE5991), *Gymnachirus texae* (Gunter, 1936) (IBUNAM:CNP:PE2521).

Cynoglossidae: *Symphurus plagiusa* (Linnaeus, 1766) (IBUNAM:CNPE:PE1733), *S. civitatium* Ginsburg, 1951 (IBUNAM:CNPE:PE8270), *S. diomedeanus* (Goode & Bean, 1885) (IBUNAM:CNPE:PE4239).

The osteological terminology follows Hoshino and Amaoka (1998); the terminology for the anal musculature follows Winterbottom (1974).

The illustrations were done by means of a *camera lucida* coupled to a stereoscopic microscope Wild M3Z.

RESULTS

Visceral cavity

The visceral cavity is relatively reduced and laterally flattened (Figs 1A, 2A). It is bounded by the scapular and pelvic girdles, the precaudal vertebrae, the first haemal spine, the pleural ribs, the first pterygiophore of the anal fin, the pectoral and pelvic musculature, and the precaudal myotomes (Fig. 2C). The precaudal vertebrae develop short haemal arches. The haemal spine of the first caudal vertebra is long and strong. The first anal pterygiophore, which is noticeably long and curved, makes contact with the first caudal haemal spine, and some other anal pterygiophores. Thus, there is a forward extension of the anal fin, as well as the advancement of the anus, urinary papilla (in females) and urogenital papilla (in males).

Kidneys are located between the haemal processes of the precaudal vertebrae and the stomach. The reproductive system lies between the digestive tract and the first anal pterygiophore.

Stomach and anterior intestine are C-shaped. The posterior intestine is bent and short. The anus opens on the blind side near the beginning of the anal fin and behind the right pelvic fin. The liver extends predominantly through the left side of the stomach.

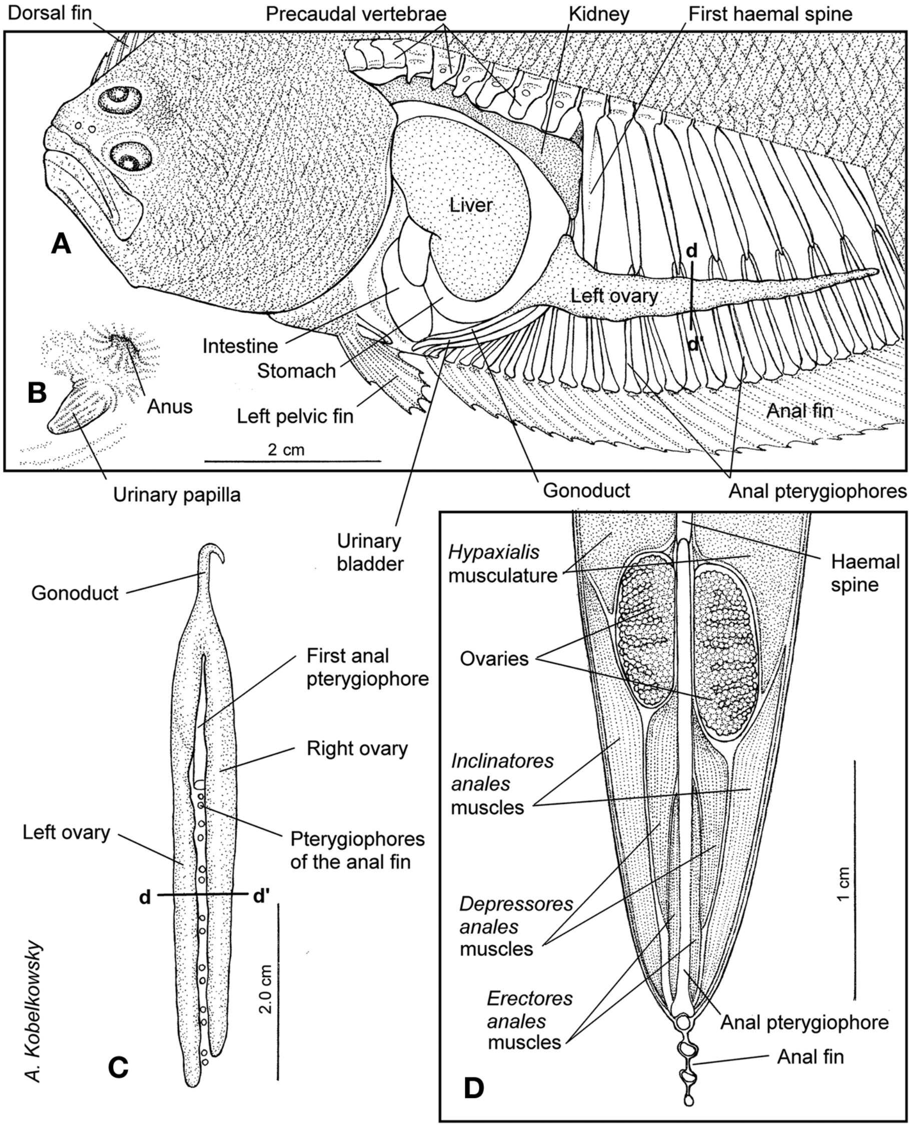

Figure 1. – Female visceral cavity of the flounder *Citharichthys spilopterus*. **A**: Left lateral view; **B**: Urinary papilla (on blind side); **C**: Dorsal view of the ovaries; **D**: Cross section of the inferior caudal region. Transect d-d' in figure A corresponds to figure D.

Gonads

Ovaries and testes are ventrally located to the posterior end of the kidneys, on both sides of the first anal pterygiophore. The curve of this long bone makes the genital and urinary ducts go forward. The female genital opening is located on the blind side of the body, between the anus and the urinary papilla. The female urinary papilla has thin longitudinal grooves (Fig. 1B).

Ovaries are laterally flattened and hollow, with the ovarian lamellae transversally oriented from the medial wall. Both ovaries grow backwards, beyond the posterior limit of the visceral cavity (Fig. 1A), between the *hypaxialis* musculature and the *inclinatores anales*, *depressores anales*, and *erectores anales* muscles (Fig. 1D). The haemal spines of the caudal vertebrae and the pterygiophores of the anal fin separate both ovaries from each other.

Both ovaries fuse together anterior to the first anal pterygiophore, from where the ovaric tunica continues forward as a gonoduct (oviduct) (Fig 1C). The urinary bladder is located paralleled to the gonoduct. Oocytes mature in the so-called ovigerous lamellae, which develop from the medial ovary wall (Figs 1D, 4A, B).

During the reproductive period, ovaries grow longitudinally backwards (Fig. 3A-E), and the GSI varies from 0.12 to 5.82 (Fig. 3). Five stages of gonadic development were observed for females (Fig. 3A-E). The first stage was observed from March to June and from October to November, with a GSI ≈ 0.18. The second from June to August and January, with a GSI ≈ 0.50. The third from August to September and from January to February, with a GSI ≈ 1.70. The fourth stage in which the ovary reaches its maximal development was observed for two individuals during March

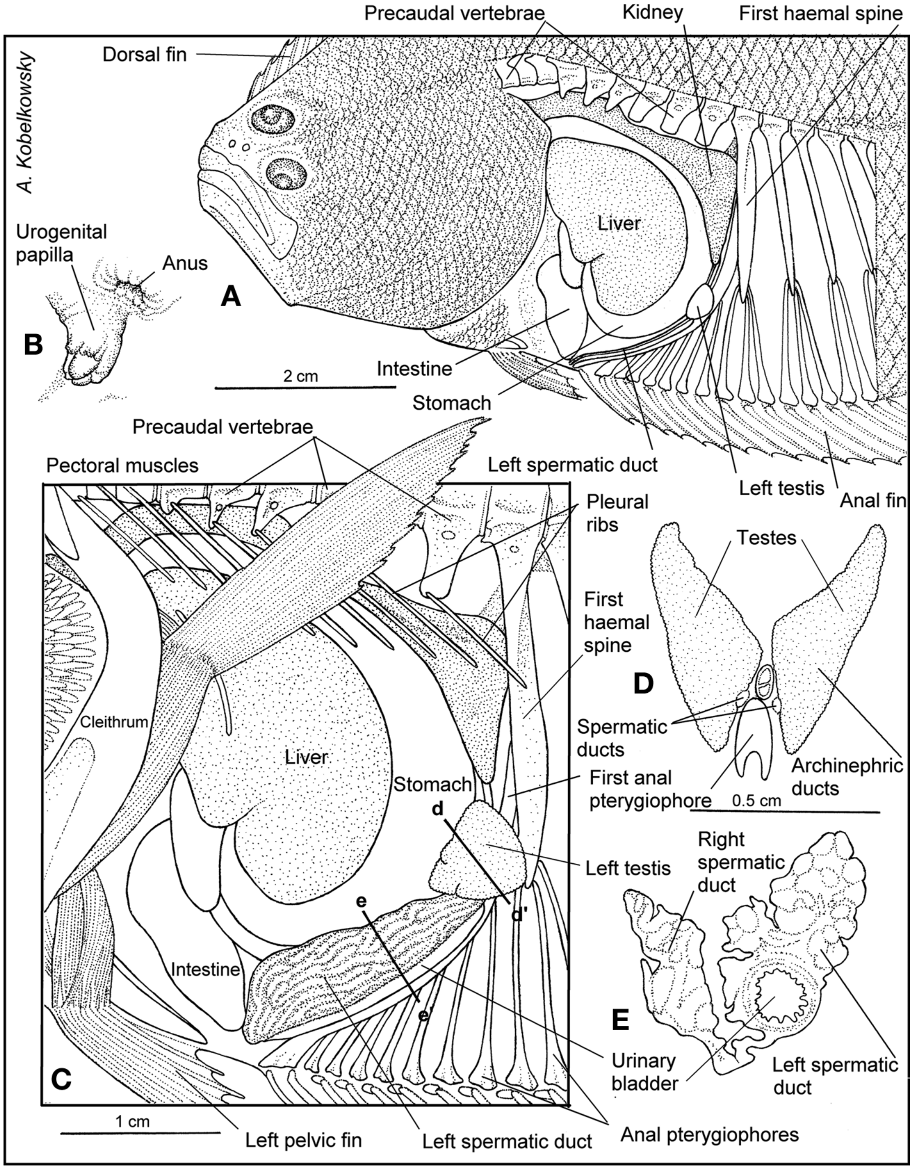

Figure 2. – Male visceral cavity of the flounder *Citharichthys spilopterus*. **A**: Left lateral view with immature testes; **B**: Urogenital papilla (on blind side); **C**: Left mature testis and spermatic duct; **D**: Cross section of testes, archinephric ducts, and first anal pterygiophore; **E**: Cross section of urinary bladder and mature spermatic ducts. Transects d-d' and e-e' in figure C correspond to figures D and E, respectively.

(mean GSI = 5.1) and for a single individual in September (GSI = 3.25). The last stage, ovaries are as deflated sacs and were observed from March to April and from October to November, with a GSI ≈ 1.20.

Testes, which are of lobular type and relatively short, with a pyramidal shape, and are located close to the place where the first haemal spine and the first anal pterygiophore overlap (Fig. 2A, C). During gonadic maturation, testes do not grow longitudinally but isodiametrically. The male GSI varies from 0.0403 to 0.4844. The spermatic ducts arise from their ventromedial surface, and go forward up to the urogenital papilla, together with the common urinary duct. The urogenital papilla has no grooves, but small lobes near the tip (Fig. 2B). The urinary bladder runs along the left spermatic duct (Fig. 2E).

Similar to females, five main stages of gonadic development were determined for males (Fig. 3F-J). The first stage was observed from March to June and November, with a GSI ≈ 0.06. The second from June to August and January, with a GSI ≈ 0.14. The third from August to October and from January to February, with a GSI ≈ 0.25. The fourth stage in which the testes achieve their maximal development was observed only from February to April, with a GSI ≈ 0.44. The last stage, testes are smaller and conducts are as deflated sacs and were observed only from February to April, with a GSI ≈ 0.33. Cross section of the mature ovary and oocytes at different stages of development are shown in figure 5A and B.

During gonadic maturation, the spermatic ducts undergo strong changes in both structure and size. At the initial

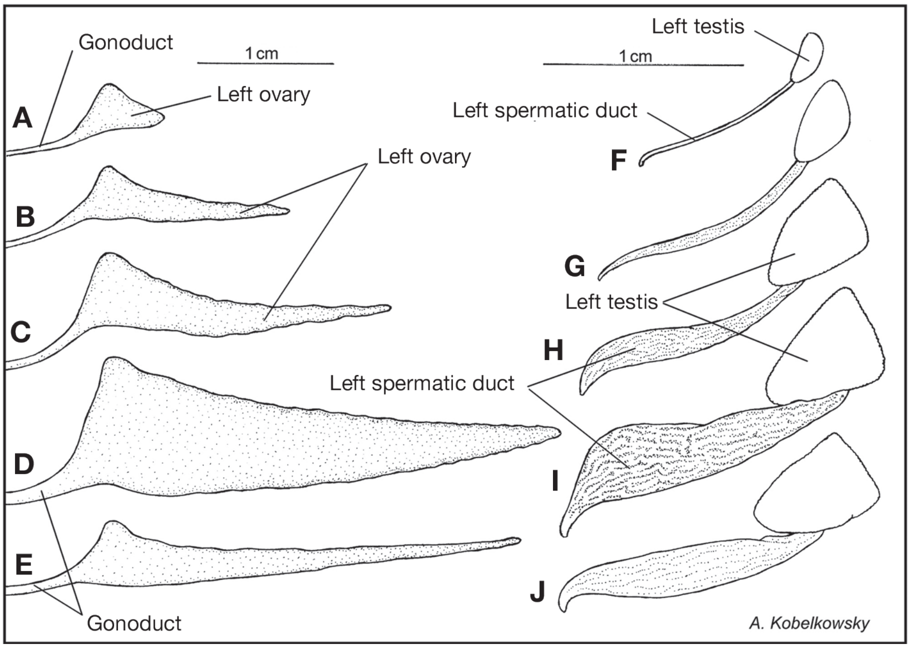

Figure 3. – Maturation of the gonads of the flounder *Citharichthys spilopterus*. **A-E**: Left side view of maturation stages of the ovaries; **F-J**: Left side view of the maturation of the testes and the spermatic ducts.

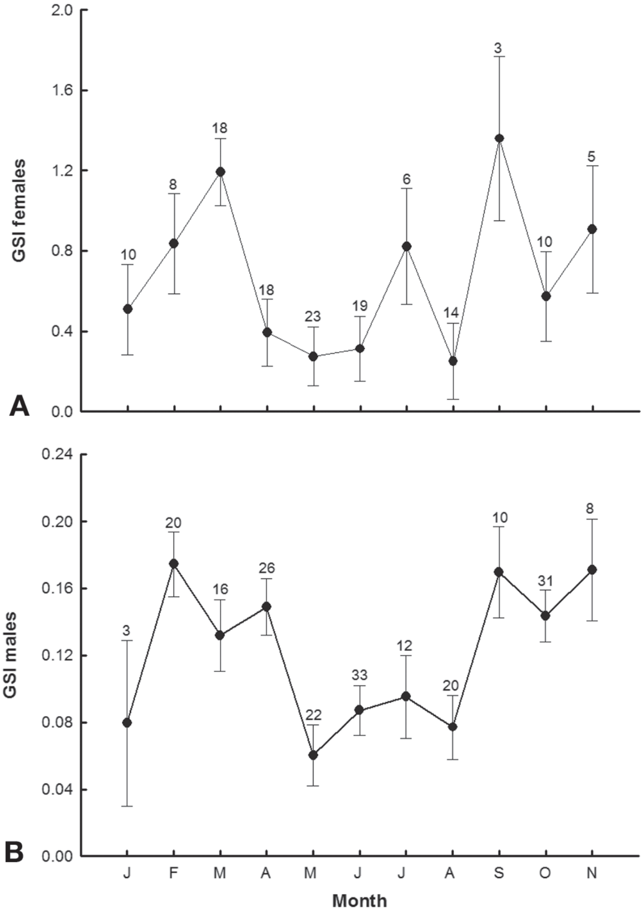

Figure 4. – Mean and standard error values of the gonadosomatic index (GSI) by month. **A**: Females; **B**: Males. The number of individuals analysed by month is indicated.

phase, each spermatic duct is simple and slim, and gradually increases in width and becomes subdivided into many anastomosed “spermatic ductules” (Fig. 3F-J). The histological analysis of the spermatic ducts shows the lumina of the spermatic ductules storing spermatozoa (Fig. 5E, F).

According to the frequency of gonadal maturation phases, testes and spermatic ducts, and the GSI of *C. spilopterus* in the lagoon of Tampamachoco, Veracruz, we assume that spawning occurs at sea.

DISCUSSION

Apparently, the visceral cavity of the Pleuronectiformes has suffered a gradual reduction in its relative size, which was already outlined in the primitive *Heteronectes chaneti* Friedman, 2008 from the Eocene and illustrated by Friedman (2012). In this species, the first anal pterygiophore is elongated and overlaps the first haemal spine, which presents an inclination that slightly passes the beginning of the base of the anal fin. The reduction in size of the visceral cavity was described in the osteological study of *C. spilopterus* by Kobelkowsky (2002), and it is observed in representative species of most of the families of living Pleuronectiformes.

Regarding this size reduction of the visceral cavity and the advancement of the anal fin, two special morphological situations are recognized: (i) reversal in orientation of the reproductive system in both sexes, and (ii) backwards and extra visceral development of the ovaries. Such situations represent a morphological pattern of the reproductive system of the Pleuronectiformes, as they are present in species of

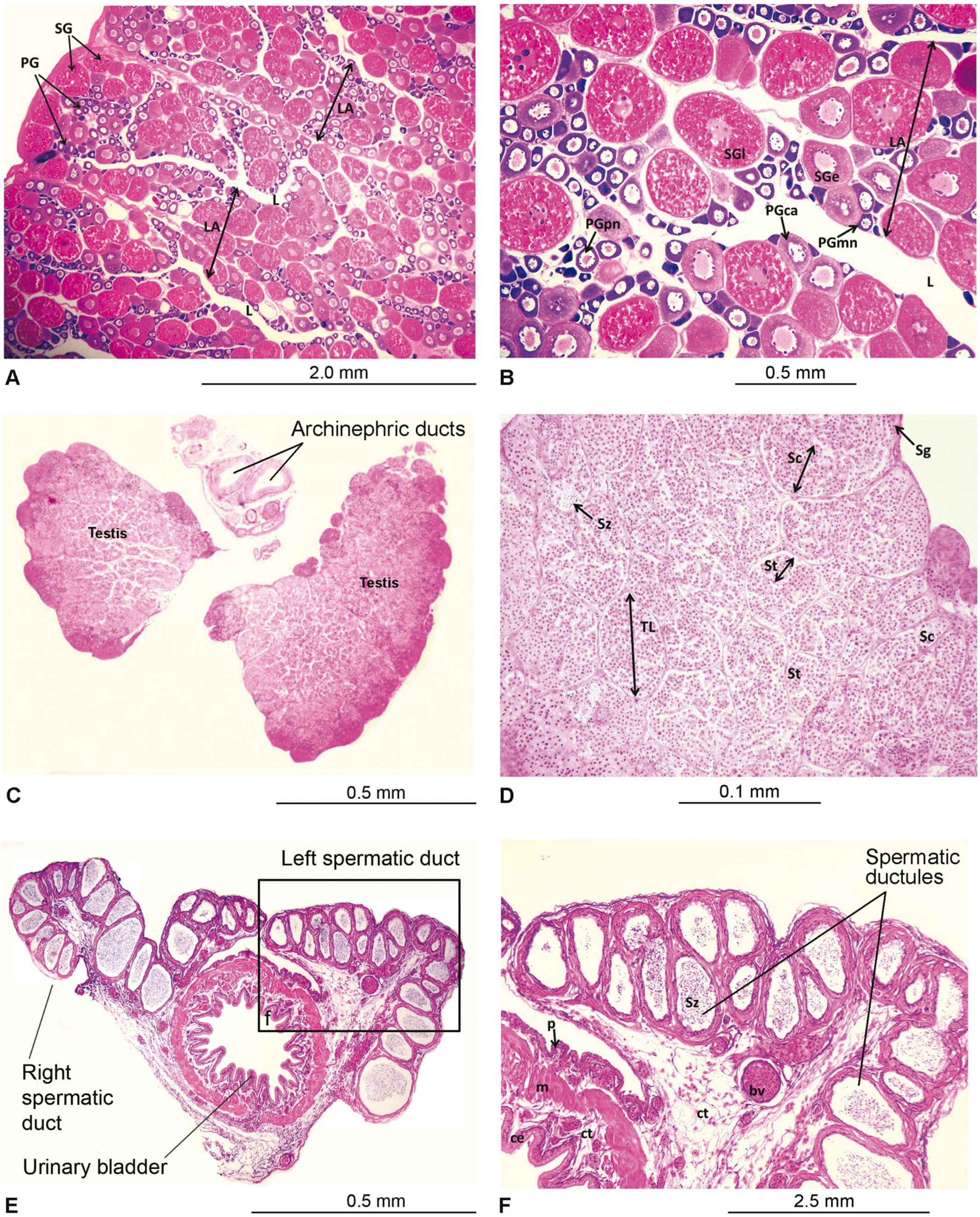

Figure 5. – Histological aspects (haematoxylin and eosin, and Masson trichrome) of the reproductive system of *Citharichthys spilopterus*. **A**: Cross section of the mature ovary (samples in March); **B**: Increased view of an ovigerous lamella showing oocytes at different stages of development (samples in January); **C**: Cross section of both testes and archinephric ducts; **D**: Organization of cysts connected by interstitial tissue of the testis; **E**: Cross section of the urinary bladder and both spermatic ducts; **F**: Cross section of the left spermatic duct showing spermatic ductules plenty of sperm (C-F, from samples in February and March). L = lumen, LA = ovarian lamellae, PG = primary growth oocytes, PGca = primary growth oocytes cortical alveoli, PGmn = primary growth oocytes nucleoli, PGpn = primary growth oocytes perinucleoli, Sc = primary spermatocytes, the double arrow limit a cyst, SG = secondary growth oocytes, Sg = spermatogonia, SGe = secondary early oocytes, SGI = secondary late oocytes, St = spermatids, the double arrow limit a cyst, Sz = spermatozoa, TL = testicular lobule; bv = blood vessel, ce = columnar epithelium, ct = connective tissue, m = muscle, p = peritoneum.

several families (Pleuronectidae, Paralichthyidae, Bothidae, Achiridae, Cynoglossidae).

The forward extension of the anal fin in the studied species implies an advanced position of the anus, the genital opening and the urinary opening in females, and the anus and the urogenital opening in males. This causes the reproductive and excretory ducts to be oriented towards the front from the gonads and the kidney, in contrast of most of teleosts, in which the reproductive ducts are oriented from the gonads towards the back.

The organization of the ovaries of *C. spilopterus* fits in the general morphological pattern of the Pleuronectiformes, described by Nagahama (1983), however, as in the rest of the Pleuronectiformes examined, the oviduct extends forwards, while the ovaries develop gradually backwards in the so-called "secondary corporal cavities" by Norman (1934). These cavities are also described by Kobelkowsky (2000) in *A. lineatus*, *T. maculatus*, and *G. texae* (Achiridae), and by Kobelkowsky (2004) in *B. robinsi* (Bothidae).

The histological organization of the testes of *C. spilopterus* corresponds to the lobular type that, according to Parenti and Grier (2004), is the characteristic of higher teleosts, in contrast to the tubular type of lower teleosts. According to Lahnsteiner and Patzner (2009), in most of the teleost species, the testes are located anteriorly to the genital papilla, and the main testicular duct goes along them in an anterior-posterior way continuing to the back. Out of the testes, these ducts are known as spermatic ducts, which join both left and right in the spermatic common duct, which discharges through the urogenital papilla. However, the reversal of the male reproductive system of *C. spilopterus* causes the testes to be located in a posterior position to the urogenital papilla, a situation which coincides with the results registered by Kobelkowsky (2000) in the Achiridae from the Gulf of Mexico and in the Bothidae (Kobelkowsky, 2004), the Soleidae (García-López *et al.*, 2005), and the Paralichthyidae (Kobelkowsky, 2007).

In teleosts with external fertilization and without accessory glands, the spermatic duct shows an internal longitudinal epithelial folding, which is intensified in a caudal direction by the fusion of the folds between themselves (Lahnsteiner and Patzner, 2009). In the present study, a similar morphological condition is observed in *C. spilopterus*, but it is noticeably greater. A similar situation is described by Lahnsteiner *et al.* (1993) in *Esox lucius* (Esocidae) during spawning.

According to the present anatomical analysis of the male reproductive system of five families of Pleuronectiformes, we recognize the multitubular character of the mature spermatic ducts as a structural pattern of Paralichthyidae, Pleuronectidae, and Bothidae, which is not present in Achiridae and Cynoglossidae.

It is recognized, as the only external dimorphic character in *C. spilopterus*, the shape of the urinary papilla in females and the urogenital papilla in males, which coincides with that registered in *Citharichthys platophrys* by Hoshino *et al.* (2004), and also in *Etropus ciadi* described by Van der Heiden and Plascencia-González (2005).

The determination of the reproductive periods of *C. spilopterus* in the Tampamachoco lagoon, Veracruz, with the highest values of the GSI shown from February to April and September, closely coincides with the ones registered for the same species by Sánchez-Gil *et al.* (2008) from February to April and from August to October in the Southern Gulf of Mexico, corresponding in both cases to the rainy and dry seasons, respectively. However, because the stage of maximal development of the testes was observed only during February-April, and the maximal development of the ovaries was more common in February-March, the first reproductive pulse (around February) is likely to be more important than the second (September). In localities from Brazil, the spawning for this species is registered in the austral summer (Chaves and Vendel, 1997; Dias *et al.*, 2005).

In addition, according to the seasonal behaviour of GSI (Fig. 4), during the first reproductive pulse, the maximal monthly mean value of the male GSI is reached in February, while the female GSI maximum is reached in March. This seems to be related to the storage capacity of the spermatic ducts, which would favour a greater production of spermatozoa and a synchrony with the maximum spawning of the females.

While in the present study, the GSI included the weight of the spermatic ducts in addition to the weight of the testes, other authors like Chaves and Vendel (1997) and Dias *et al.* (2005) do not calculate this index in males, due to the relatively reduced size of testes of *Citharichthys* species.

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